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Performance evaluation of Nanoparticle-Modified Asphalt Binders

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ABSTRACT
Traditional tests (penetration, ductility, and softening point) and a dynamic shear rheometer were used to characterize the physical and rheological properties of asphalt binder (DSR). Calcium carbonate nanoparticles (CaCO3) and aluminum hydro oxide (Al2O3) nanoparticles were introduced to the basic asphalt at concentrations of 3, 5, and 7% by weight of asphalt, respectively, in this investigation. The addition of CaCO3 and Al2O3 content to the asphalt has a considerable effect on the physical properties of the asphalt, with penetration reduced by up to 50% for CaCO3 modified asphalt and 64% for Al2O3 modified asphalt. When compared to the base asphalt binder, the softening point of modified asphalt binders increased by 11 and 12 percent for both modifiers, respectively.
The results also revealed that the storage stability of modified asphalt binders containing CaCO3 and Al2O3 nanoparticles was less than 2.5 °C, indicating that the asphalt binder and modifiers are highly compatible. The stiffness (G*) of modified asphalt binders was enhanced with the addition of both modifiers, and the highest performance of asphalt binder was obtained with the addition of 5% of both nanoparticles. As a result, the usage of CaCO3 and Al2O3 nanoparticles as an alternative additive to change asphalt binder can be considered.
Keywords: Calcium carbonate nanoparticles; Dynamic shear rheometer; Modified asphalt binder; Storage stability

I. INTRODUCTION

Asphalt is a dark brown to black cementation material made primarily of bitumen, which can be found in nature or manufactured through petroleum processing. Asphalts are viscous liquids or solids that are mostly made up of hydrocarbons and derivatives that are soluble in carbon disulfide [1,2]. They are relatively nonvolatile at room temperature and progressively soften when heated. Asphalt has been utilized for thousands of years, and its significance as a valuable engineering material is growing. Because bitumen is commonly utilized in the construction of motorways and road networks, asphalt should be able to withstand traffic loads and low temperatures[three]. Due to the limitations of temperature susceptibility, the asphalt's low, middle, and high temperatures, as well as its temperature performance, must be improved. As a result, modifying the base asphalt is required to increase the material's performance.

II. LITERATURE REVIEW

FA is a highly dispersible powder. It contains mainly alumino silicate and ferriferrous glassy spherical particles (about 60 - 80%) and irregularly shaped grains of amorphous clay, mullite quartz and unburned metamorphic fuel (Malhotra and Ramezaniarpour, 1994; Diamond, 1986).
BA consists of irregular particles, which can be up to 10-15 mm in size. The chemical compositions of FA and BA ashes from the same power plant are similar (Yun et al., 2004).
Depending on the cooling conditions, the glassy or crystalline phase can be predominating in BA (Nisnevich et al., 2001).
As a rule, BA is inert and can be used as aggregate for producing construction materials such as mortar and concrete. In addition, BA can be used directly as aggregate in road construction (Bruder-Hubscher et al., 2001).
Fly ash obtained from coal combustion is frequently used in concrete as a cost-effective substitute for portland cement. The pozzolanic properties of fly ash improve the strength of concrete, and its small spherical particles make the concrete mixture more workable (Pei- wei et al.,

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2007).

Extensive research and development works have been done on the use of fly ash as a component of concrete (Aitcin and Laplante, 1992; Fernández-Jiménez et al., 2006; Chindaprasirt et al., 2007), and on the changes that its incorporation induces in both mechanical (Topcu and Canbaz, 2007) and thermal (Demirboga, 2007) properties. Moreover, Lingling et al. (2005) found that fly ash improves the compressive strength of bricks and makes them more resistant to frost attack. Cicek and Tanriverdi (2007) also observed the positive effect of fly ash on the compressive strength of bricks.

. Several studies have been carried out in Germany, England, and China to produce bricks from fly ash (Guler et al., 1995; Kalwa and Grylicki, 1983; Mukherji and Machhoya, 1993; Lingling et al., 2005).

Experimental Design

Materials

Materials were used to produce some laboratories mixed; Basebitumen binder used in this study was 60/70 penetration grade, while the nonmaterial's were aluminum oxide nanoparticles (Al2O3) and Calcium Carbonate nanoparticles (CaCO3) white powder were supplied from China. The physical properties of the base bitumen binder and nanoparticles are shown in (Table 1 & Figure 1).

Figure 1: Modifiers of asphalt binder (a) Al2O3 nano particles (b) CaCO3 nano particles.

Table 1: Physical properties of the base asphalt and nano particles.

Material	Properties	Test Method	Value
	Specific Gravity	ASTM D70	1.03
	Penetration @ 25 ˚C	ASTM D5	82
Bitumen	Softening point (˚C)	ASTM D36	46
60/70	Viscosity @ 135 ˚C (Pa.s)	ASTM D4402	0.24
	Ductility (cm) @ 25 ˚C	ASTM D113	≥100
CaCO3	Size nm	-	40
	form		Powder
Al2O3	Size nm	-	13
	Form		Powder

Preparation of modified asphalt binders

The base bitumen was heated to 150 °C and stirred for about 10 min, and the temperature was raised up to 170 °C. Three percentages of both modifiers (3,5 and 7% by weight) were added gradually to the base asphalt binder with constant stirring at 170 °C under the high shear mixture speed of 5000rmp for 90min until it achieves a homogenous asphalt binder blend for each percentage respectively.

Testing Procedures

Physical properties

The conventional physical tests, penetration test at 25 °C, Softening point (Ring and Ball) and ductility were conducted according to the American Society for Testing and Materials (ASTM); ASTM D5, ASTM D36, and ASTM D113 respectively.

Storage stability test

The modified asphalt cement storage stability was measured as follows. The samples were poured into an aluminum foil tube; the height of the tube is 16cm in with 3cm in diameter. The foil tubes were closed and stored vertically at a temperature of 163±5 °C in an oven for 48 hours, therefore cooled at room temperature and divided horizontally into three equal parts. The samples taken from the upper and lower sections were used to assess the storage stability of the ASA modified asphalt cement by determining the sections softening points, if the difference between the top and the bottom parts was less than 2.5 °C, then the samples were considered to have excellent high-temperature storage stability. If the softening points differed by more than 2.5 °C, the ASA modified asphalt binder was considered to be unstable [12,13].

Dynamic shear rheometer (DSR)

Dynamic Shear Rheometer (DSR) is used to determine the rheological properties of asphalt binder, including complex shear modulus (G*) and phase angle (δ), at low, intermediate and high temperatures. These parameters can be used to describe both viscous and elastic behavior of asphalt. The values of G* and for asphalt binder are highly dependent on the test temperature and frequency of loading. G* is a measure of the total resistance of a material to deformation when exposed to a sinusoidal shear stress load. G* consists of both elastic and viscous components. The δ is an indicator of the relative amounts of viscous and elastic elements. The DSR used investigates the rheological properties of CaCO3 and Al2O3 nanoparticles modified asphalt binders using a frequency sweep test. The frequency sweep applied was 0.159 to 15 Hz, and the temperatures within range 45+10 to 75 ˚C. One plate was used in the test, 25 mm diameter spindle with a gap of 1 mm.

III. RESULTS AND DISCUSSION

Physical properties

The penetration value was reduced for all modified binders at 25 °C compared with the base asphalt binder. The reduction in the penetration value for modified asphalt binders with CaCO3 was 44.8mm to 3%, 35.4 mm for 5% and 42.4 for 7% respectively. Meanwhile, it was observed that the reduction in modified binders with Al2O3 nanoparticles was. The maximum decrease in the penetration was noted with 5% for both modifiers compared with all asphalt binders. Furthermore, modified asphalt binders give a Higher softening temperature compared with base asphalt binder as shown in (Figure 2). Meanwhile, the base asphalt binder has the lowest softening point temperature. The decrease in penetration and an increase in the softening point of modified asphalt binders are a result of the stiffening effect of nanoparticles. In general, the addition of nanoparticles able to enhance the properties of base asphalt up to 5% of modifier, in the meantime concentration of 7% shows different behavior as the penetration increase and softening point decreased. It might be due to agglomeration of nanoparticles during the mixing process [14].

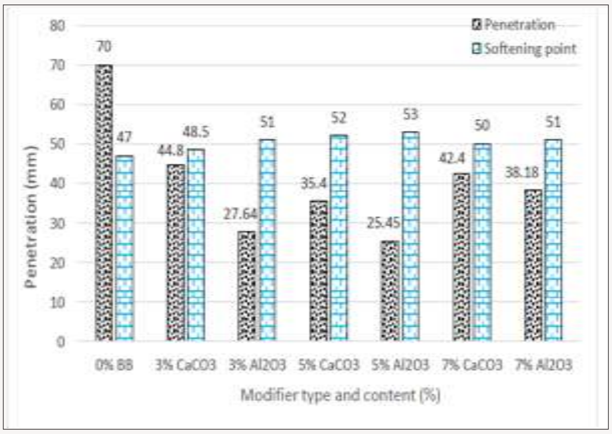

Figure 2: Penetration and softening point of modified asphalt binders.

Storage stability of modified asphalt binders

The difference in softening point values between the up and down sections of asphalt binders indicates its storage stability. The less value of the parts, the better storage stability for the modified asphalt binders [15]. (Figure 3) shows the storage stability of the base asphalt binder and modified asphalt binders. It was found that the differences in softening points in modified asphalt binders were 1 °C. Therefore, measuring the softening point of the up and bottom sections of each sample, show that the differences between the top and bottom pass the required value as it is less than 2.5 °C for all binders, this indicates that the nanoparticles modified asphalt binders were quite stable during stored at high temperatures.

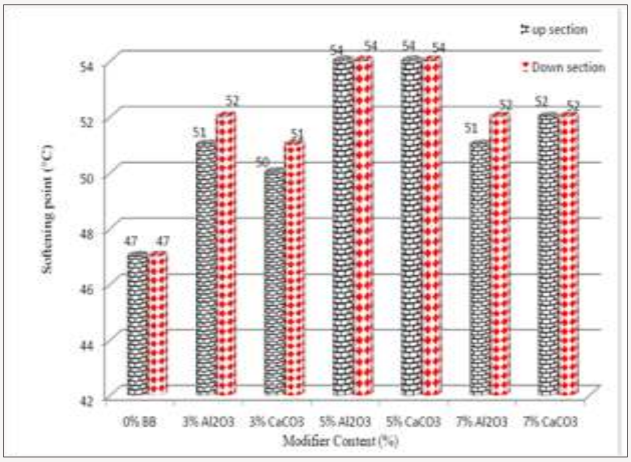

Figure 3: Storage stabilities of modified

The dynamic shear rheometer (DSR)

Modify of asphalt binder usually perform in two types of the binders, regarding the compatibility between asphalt and the modifier; and the modifier are entirely compatible [16]. The evaluation of rheological properties of modified asphalt binder shows a significant improvement in the performance of asphalt binder. (Figure 4) shows that the addition of modifier increases the stiffness of modified asphalt binders. It the first one, a heterogeneous blend, the asphalt binder, and modifier are incompatible, and they are separated into two phases. The second one is a homogeneous blend, asphalt binder, was noted that the modified asphalt binders whit Al2O3 nano particles have the highest complex shear modulus among the binders, which mean the highest resistance to deformation at elevated temperatures. Wearase, the base asphalt binder has the lowest complex shear modulus.

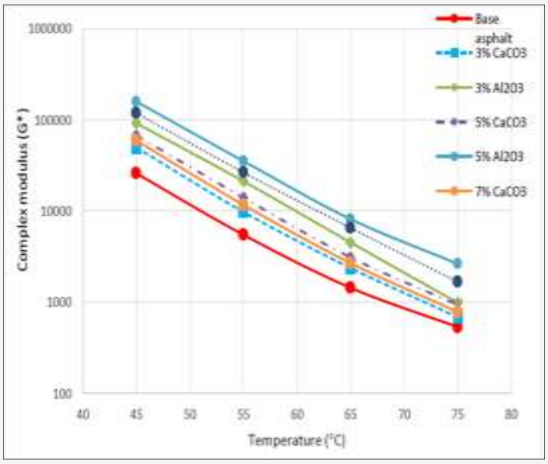

Figure 4: Isochronal plots of modified

IV. CONCLUSION

The evaluation of physical and rheological properties of asphalt binder shows that both modifiers have been successfully improved the physical and rheological properties of modified asphalt binders compared with base asphalt. Main points are listed as:-

- The penetration decreased and softening point increase, which means the modified bitumen binders become harder compared with base asphalt, and the hardness of binders leads to reduce the temperature susceptibility. Also, it was found that the compatibility between asphalt and nanoparticles is significant, it might due to the uniform dispersion of nanoparticles in the asphalt blends.
- The result shows that 5% of both modifiers of asphalt binder can be considered as the best performance of asphalt binder. From the mixing and preparation of nano- and micro-modified asphalt binders, it is deduced that the nano- or micro-materials may have chemical reactions and physical dispersion with the control asphalt.
- From the DSR results, the addition of NI.44P, MCF and NMN materials can increase the complex shear modulus of these modified asphalt binders relative to the control asphalt binder, and improve the resistance to rutting, however, the complex shear modulus of PMN modified asphalt binder decreases and the recovery ability of PMN modified asphalt binder may be enhanced.
- FTIR spectroscopy shows the addition of nano- or micro-materials in the asphalt binder, the oxidation reaction may be weakened in the modified asphalt binder when it is exposed to sunlight and heat. In summary, the effect of modified asphalt binder on anti-oxidation is improved when the selected nano- or micro-materials were added in the control asphalt.
- For future work, the asphalt mixture tests and model simulation are planned for evaluating the macro-scale properties of modified asphalt mixtures.

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